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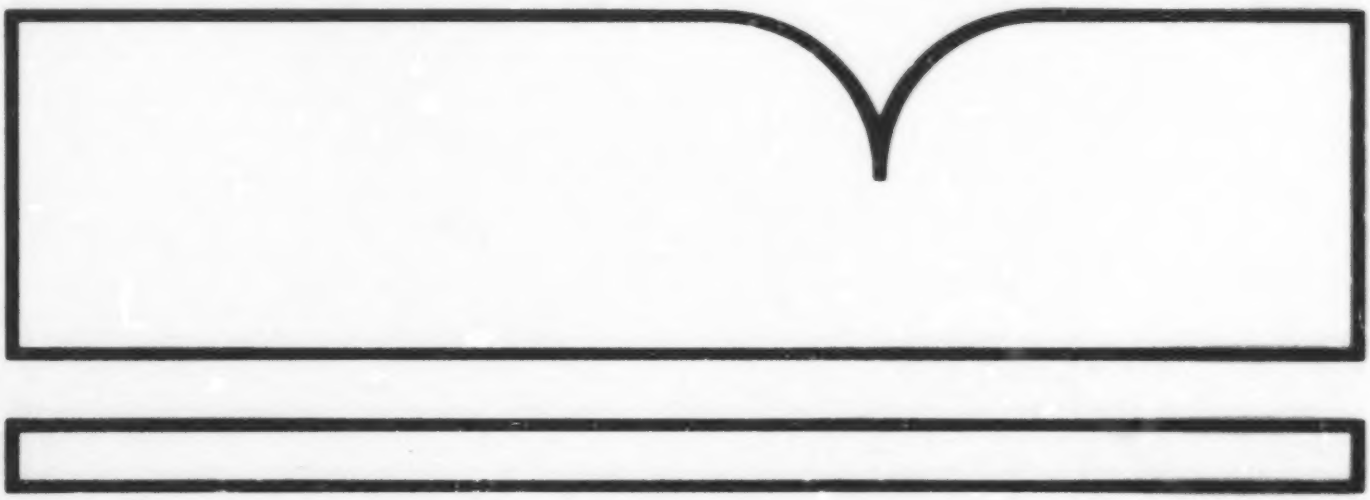

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DEFINITION OF THE LONG-TERM CONTROL EFFICIENCY OF CHEMICAL DUST SUPPRESSANTS APPLIED TO UNPAVED ROADS

by

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17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
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Dust Control	Cost Effectiveness	Stationary Sources		14A
Roads	Particles	Dust Suppressants		14G
Water	Dust	Unpaved Roads	07B	11G
Petroleum Products		Petroleum Resin	11G	
Asphalts	Toxicity	Particulates	08G, 13C	06T
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DEFINITION OF THE LONG-TERM CONTROL EFFICIENCY OF CHEMICAL DUST SUPPRESSANTS APPLIED TO UNPAVED ROADS

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ABSTRACT

This paper presents the methodology and results of a field testing program directed toward quantifying the long-term efficiency of chemical dust suppressants applied to industrial unpaved roads. Three generic categories of suppressants were evaluated: water, a water-based petroleum resin, and a water-based asphalt emulsion. The latter two suppressants were the most frequently mentioned in discussions with iron and steel companies. Watering was also selected because of its widespread use and to compare its effectiveness to that of the chemicals.

Knowledge of the long-term performance of dust suppressants is of vital importance in determining a cost-effective program for reducing emissions from open dust sources. The information presented in this paper enables one to determine cost-effectiveness values for the chemicals evaluated.

Trace element analysis of uncontrolled particulate emissions from unpaved roads is also presented. Because open-source dust emissions may be used to offset process emissions on a strict mass basis, information about concentration levels of toxic components in dust emissions is of importance in credibly implementing the Environmental Protection Agency's (EPA's) Bubble Policy.

INTRODUCTION

There is strong evidence that open dust sources (such as vehicular traffic on unpaved and paved roads, aggregate material handling, and wind erosion) could occupy a prime position in particulate emission control strategy development in the iron and steel industry.[1,2,3] This conclusion is based on comparisons between industry-wide uncontrolled emissions from open dust sources and typically controlled fugitive particulate emissions from major process sources such as steelmaking furnaces, blast furnaces, coke ovens, and sinter machines. Preliminary cost-effectiveness (dollars expended per unit mass of reduced particulate emissions) analysis of promising control options for open dust sources indicated that reducing emissions from these sources might result in significantly improved air quality at a lower cost compared to additional reductions of process source emissions.

With the publication of the EPA's Bubble Policy (Alternative Emissions Reduction Options) in the December 11, 1979, Federal Register (proposed revisions published April 7, 1982), the steel industry has recognized the economy of controlling open dust sources as compared to implementing more stringent control of process stack and fugitive particulate emissions. At the time of this writing, five emission reduction plans (bubbles) in the iron and steel industry involving open dust sources have been published in the Federal Register. The affected plants and the dates the proposed or final rules appeared are shown below:

Plant	Date	Status
Armco-Middletown Works	March 31, 1981	Final Rule
Shenango-Neville Plant	December 29, 1981	Final Rule
National-Weirton Steel Division	December 9, 1982	Final Rule
National-Granite City Steel Division	December 17, 1982	Proposed Rule
National-Great Lakes Steel Division	December 17, 1982	Proposed Rule

This paper presents long-term emission control efficiency decay curves for chemical dust suppressants applied to unpaved roads at iron and steel plants. The testing program described in this paper is a continuation of MRI's pioneering work in the control of emissions from open dust sources in the iron and steel industry.[3,4] While the earlier study indicates that the control of particulate emissions from this type of source is more cost-effective than controlling process source emissions, this paper presents the first step in quantifying the long-term performance and cost-effectiveness of dust suppressants applied to unpaved roads. Such long-term data are necessary in order to accurately represent the controlled emission rate for an open dust source as part of an emissions reduction plan based on the Bubble Policy. This type of information is also required in examining the optimal cost-effectiveness of a control measure. Because of the similarity of unpaved roads in a variety of industries, the results presented in this paper are applicable to several industries in addition to iron and steel.

Three generic categories of suppressants were evaluated: water, a water-based petroleum resin, and a water-based asphalt emulsion. The latter two were the most frequently mentioned chemical suppressants in discussions with iron and steel companies.[5] Watering was also selected because of its widespread use and to compare its effectiveness to that of the chemicals.

One factor affecting the performance of a dust suppressant is the size (diameter) of the emitted particles being considered. On a microscopic level, variation in

control efficiency for different size particles may be viewed as a result of variation of bonding forces for particles with different surface-area-to-volume ratios. Very few data are available to predict how the efficiency of a specific suppressant will vary with the size of the emitted particles. Prior MRI testing suggests that the suppressant's effectiveness for reducing finer particle emissions is less than that for larger particles.[3] The particle size ranges studied are:

TP	Total airborne particulate matter.
IP	Inhalable particulate matter consisting of particles smaller than 15 μm in aerodynamic diameter.
PM_{10}	Particulate matter consisting of particles smaller than 10 μm in aerodynamic diameter.
FP	Fine particulate matter consisting of particles smaller than 2.5 μm in aerodynamic diameter.

Finally, selected samples taken during the uncontrolled tests were analyzed for trace metals. Dust emissions may currently be traded on a strict total mass basis for process emissions. Information on the particle size distributions and the concentration levels of specific toxic components provides a basis for determining the need for future revisions to the Bubble Policy.

TEST PROCEDURE AND DESCRIPTION

This section presents the test procedure and site description for this study. The following topics are discussed: (1) study design; (2) site description; (3) quality assurance; and (4) dust suppressant effectiveness calculation procedure.

Study Design

In developing a study design to characterize unpaved road dust suppressant effectiveness, both a sampling methodology and a suppressant application plan must be chosen. The sampling method must be able to accurately characterize the dust emissions, and the suppressant application plan

must be developed with attention paid to possible interference effects which could impact determining the suppressants' effectiveness.

Unpaved road dust emissions are especially difficult to characterize for the following reasons:

1. Both uncontrolled and controlled emission rates have a high degree of temporal variability.

2. Emissions consist of a wide range of particle sizes (including coarse particles which deposit immediately adjacent to the source). The suppressants' effectiveness can vary substantially, depending on the size of the particles.

The scheme for quantification of emission factors must effectively deal with these complications to yield source-specific emission data needed to evaluate the priorities for emission control and the effectiveness of emission suppressants.

Two basic techniques have been used in quantifying particulate emissions from vehicular traffic on unpaved roads:

1. The upwind/downwind method involves measurement of concentrations upwind and downwind of the source, utilizing ground-based samplers (usually hi-vol samplers) under known meteorological conditions. Atmospheric dispersion equations are used to back-calculate the emission rate which most nearly produces the measured concentrations. The Gaussian dispersion equations are often applied to cases of near-roadway dispersion. However, the equations generally used were not formulated for such an application.

2. MRI's exposure-profiling method involves direct measurement of the total passage of open dust source emissions immediately downwind of the source by means of simultaneous multipoint sampling over the effective cross section of the open dust source emission plume. This technique uses a mass-balance calculation scheme similar to EPA Method 5, rather than requiring indirect calculation through the application of a generalized atmospheric dispersion model.

In addition to the above measurement techniques, the study design must also include a suppressant application plan. Two major types of plans have been used:

1. Testing is conducted on two or more contiguous road segments. One segment is left untreated, and the others are treated with a separate dust suppressant.

2. Uncontrolled testing is initially performed on one or more road segments. These segments are then treated with different chemicals, and there is no segment left untreated as a reference. A normalization of emissions is required to allow for differences in vehicle characteristics during the uncontrolled and controlled tests which do not occur simultaneously.

Because of the two choices each for sampling method and control application plan, there are four possible study designs. The first control application plan allows concurrent testing of controlled and uncontrolled emissions. Significant variation in the uncontrolled road surface, from segment to segment, would distort the results. Also, it is necessary that a long road be available in order to accommodate the additional uncontrolled segment and to ensure that the control efficiency associated with a treated segment is not affected by the track-on of dust from neighboring uncontrolled segments. None of the candidate test sites at surveyed plants had road lengths amenable to this plan. Consequently, control plan 2 listed above was selected.

A measurement technique was then required to complete the study design. Because the cost-effectiveness of a control measure cannot be calculated without reliable uncontrolled emission factors, an accurate technique is required to quantify particulate emissions. The most suitable and accurate technique for quantifying unpaved road emissions in the iron and steel industry has been shown to be exposure profiling.[1] The method is source-specific and its increased accuracy over the upwind/downwind method is a result of the fact that emission factor calculation is based on direct measurement of the variable sought; i.e., mass of emissions per unit time.

Thus, the study design used in this testing program employed exposure profiling to first quantify uncontrolled particulate emissions from vehicular traffic on unpaved roads and to then determine control efficiency from normalized controlled emission factors. This design allowed MRI to accurately determine not only the control performance but also the cost-effectiveness of the dust suppressants evaluated.

Site Description

An asphalt emulsion was evaluated at Jones and Loughlin (J&L) Steel's Indiana Harbor Works, while watering and a petroleum resin were tested at Armco's Kansas City Works. J&L initiated an experimental open dust emission reduction program just before the onset of the field testing. The test road at the Indiana Harbor Works was not treated until MRI had conducted uncontrolled tests to establish a baseline for emissions. Following these tests, MRI personnel supervised the application of the suppressant on the test road. Application of the dust suppressant at the Kansas City site was contracted and closely regulated by MRI.

Quality Assurance

The sampling and analysis procedures followed in this field testing program were subject to certain quality assurance guidelines. Affected areas included: (1) auditing procedure for gravimetric analysis of filters; (2) filter handling procedures in the field and laboratory; (3) equipment flow rate calibration technique and frequency; (4) field data recording procedures; (5) standard procedures for physical analysis of road aggregate; and (6) calculation techniques and accuracy. A detailed description of the quality assurance procedures can be found in the final report.[5]

Suppressant Effectiveness Calculation

Although tests with and without suppressants were conducted at the same site, it was necessary to obtain normalized values of emission factors in order to make meaningful comparisons. This is true simply because the vehicle mix on the test road varied not only from day to day but also during different shifts during individual days. Thus, measurement-based

emission factors required normalization in order that a change in vehicle mix was not mistakenly interpreted as part of the efficiency of the suppressant being tested.

The method used in this study to normalize emission factors was based on MRI's experimentally determined predictive emission factor equation for emissions from vehicles traveling on unpaved roads.[2] Basically, average vehicle weight, number of wheels, and speed during a test were compared to a standard set of values and the comparison used to normalize the measurement-based emission factors.

The control efficiency c (in percent) for a given test is then calculated as follows:

$$c = \left(1 - \frac{e_c}{\bar{e}_u}\right) x \quad 100\% \qquad (1)$$

where: e_c = normalized emission factor for controlled road for a given test

$\bar{e}_u$ = geometric mean of normalized emission factors for uncontrolled roads

ANALYSIS OF FIELD TEST RESULTS

Long-Term Suppressant Efficiencies

Three suppressants used to reduce unpaved road dust emissions were evaluated during the study: (1) a 20% solution of an emulsified asphalt applied at an intensity of 3.2 ℓ/m^2 (0.70 gal/yd^2); (2) water applied at an intensity of 2.0 ℓ/m^2 (0.43 gal/yd^2); and (3) a 20% solution of a petroleum resin applied at an intensity of 3.8 ℓ/m^2 (0.83 gal/yd^2), followed by a repeat application of 4.5 ℓ/m^2 (1.0 gal/yd^2) of 12% solution 44 days later. The results presented in this report are only directly applicable to these dilution ratios and application intensities which, for the chemical dust suppressants, were recommended by the manufacturers. These application parameters are, in general, much higher than those currently used at iron and steel plants.

Table I presents the least-squares fit of control efficiency as a function of number of vehicle passes following application for the dust suppressants evaluated during this study. It should be noted that the decay in the efficiency of a chemical control is primarily a function of vehicle passes and is only indirectly dependent on time because traffic is itself a function of time. Also shown in Table I are statistics that determine the level of significance of the equation as well as source/application parameters that affect the suppressant's performance.

In the case of the linear control efficiency (dust suppressant effectiveness) decay functions shown in Table I, the time T (in days) required between applications to achieve an average control efficiency C is:

$$T = \begin{cases} \frac{2}{mR_T} (a - C), & a \geq C \geq \frac{a}{2} \\ \frac{a^2}{2mR_T C}, & \frac{a}{2} \geq C > 0 \end{cases} \qquad (2)$$

where:

a = intercept of the decay curve (%)
m = decay constant (%/vehicle pass)
R_T = traffic rate on road of interest (vehicle passes/day)

The asphalt emulsion was tested over a period of approximately four months and nearly 50,000 vehicle passes. TP emissions showed the lowest initial control efficiency. The control efficiency values associated with particulate emissions in the smaller size ranges, however, showed a much greater rate of decay than that for TP. The most extreme example of differing decay rates occurs during the comparison of TP and FP control efficiencies. Initial FP control was substantially greater than that of TP, but a sharp decrease in FP control efficiency occurred with the result that FP emissions nearly match the uncontrolled state at a time when TP emissions were still controlled at the 50% level.

The tests of watering of unpaved roads indicated high initial control efficiency which decreased at a rate of approximately 8% per hour. The rate of control efficiency decay was found to decrease as the size range of particulate emissions decreased.

TABLE I. DUST SUPPRESSANT EFFICIENCY AS A FUNCTION OF VEHICLE PASSES

Suppressant	Time After Application	Average No. of Vehicle Passes per Day	Mean Vehicle Parameters: Weight (Mg)	Weight (tons)	No. of Wheels	Particle Size Range	Least-Squares Fit of Control Efficiency[a] (%)	Correlation Coefficient	Level of Significance
Asphalt Emulsion 3.2 ℓ/m² (0.70 gal/yd²) of 20% solution in water	2-116 days	410	27	30	9.2	TP	92.9-0.000800 V	-0.913	99%
						IP	102-0.00129 V	-0.915	99%
						PM_{10}	102-0.00113 V	-0.921	99%
						FP	100-3.54 (10^{-6}) V^2	-0.986	99.9%[b]
Petroleum Resin - initial application 3.8 ℓ/m² (0.83 gal/yd²) of 20% solution in water	7-41 days	94	34	38	6.2	TP	79.1-0.0139 V	-0.717	< 90%
						IP	92.2-0.0144 V	-0.869	95%
						PM_{10}	94.9-0.0134 V	-0.892	98%
						FP	102-0.0127 V	-0.796	90%
Petroleum Resin - reapplication 4.5 ℓ/m² (1.0 gal/yd²) of 12% solution in water	4-35 days	97	39	43	6.0	TP	97.0-0.00225 V	-0.648	< 90%
						IP	99.1-0.00375 V	-0.958	95%
						PM_{10}	100-0.00430 V	-0.960	95%
						FP	100-0.00568 V	-0.890	< 90%
Watering 2.0 ℓ/m² (0.43 gal/yd²)	0-2.8 hr	1,200	44	49	6.0	TP	103-0.209 V	-0.958	N/A
						IP	102-0.187 V	-0.969	N/A
						PM_{10}	102-0.179 V	-0.963	N/A
						FP	101-0.156 V	-0.990	N/A

[a] V represents cumulative vehicle passes after application. Complete mitigation is assumed immediately after application.

[b] Because a parabola was used to characterize FP control efficiency decay, standard tests of significance are not strictly applicable.

The tests of an initial application of a petroleum resin product did not indicate significant variation in the control efficiency decay rate as a function of particle size range. During each test in the 41 day period after application, the measured control efficiency increased as the particle size range decreased. Unlike the asphalt emulsion, the petroleum resin appeared to control particulate emissions of different size fractions in a consistent manner throughout its lifetime. In other words, the decay rate for the initial application of the petroleum resin was nearly identical regardless of the particle size.

The tests of the reapplication of the petroleum resin provided strong indication of a residual effect from the initial application. Figure 1 compares the PM_{10} control efficiency decay functions for the initial and repeat applications. As shown in Figure 1, the rate of decay for the repeat application was found to be roughly an order of magnitude less than that associated with the initial application. Comparison of the surface aggregate size distribution before and after chemical retreatment (Table II) suggests that the bonding characteristics of the reapplication are enhanced by a residual effect of the initial treatment.

Chemical Analysis of Selected Samples

Trace element analysis of uncontrolled particulate emissions from unpaved roads in the iron and steel industry was also conducted during the course of this study. Because this type of emissions may be used to offset process emissions on a strict mass basis, information on the concentration levels of specific toxic components in the road dust emissions is of importance in credibly implementing the Bubble Policy.

Twenty-six samples, consisting of 12 exposed filters and 14 road surface silt samples, were analyzed for trace metals using inductively coupled plasma (ICP) emission spectroscopy. Both filter and surface samples consisted of two different size fractions. In addition, five blank filters were analyzed.

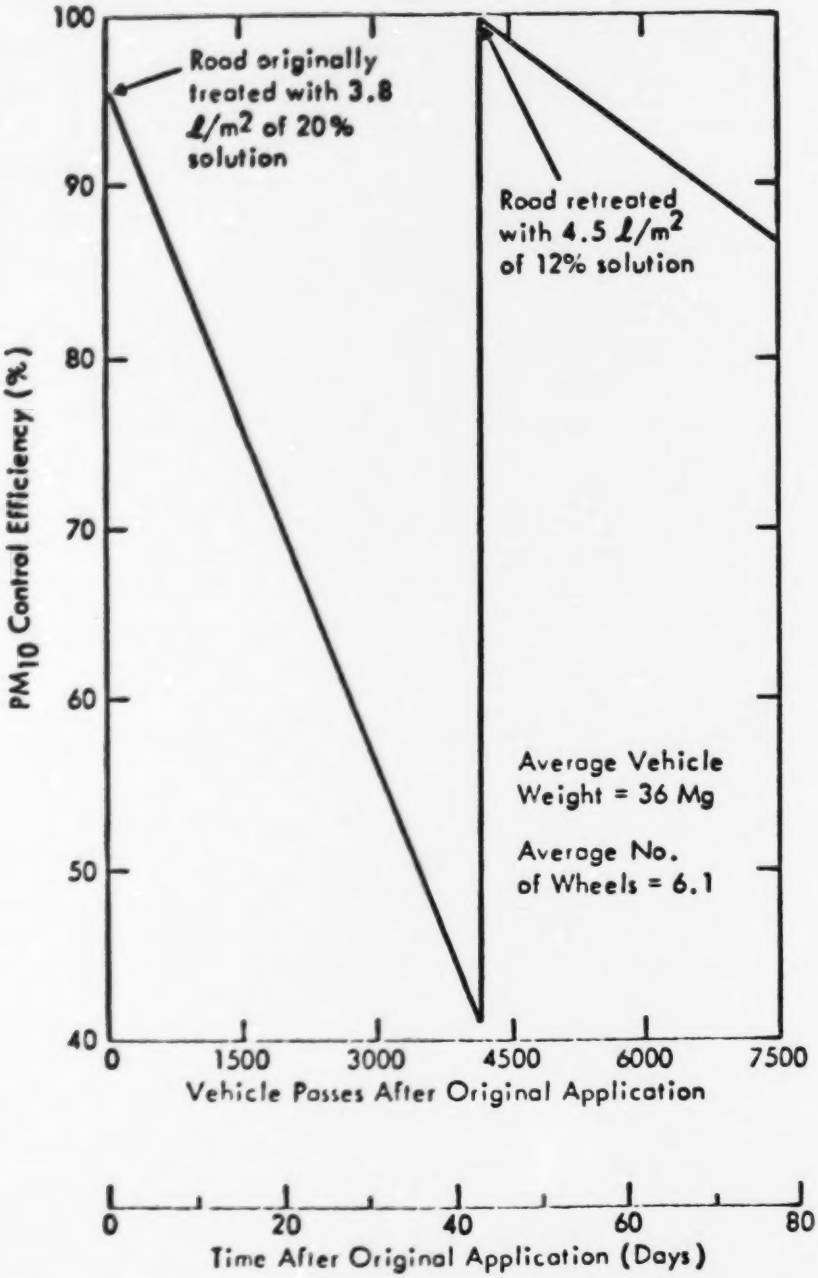

Figure 1. Comparison of the control performance for PM_{10} of an initial and a repeat application of a petroleum resin illustrating the residual effect.

TABLE II

COMPARISON OF SURFACE AGGREGATE SIZE DISTRIBUTION BEFORE AND AFTER PETROLEUM RESIN REAPPLICATION

Physical Particle Size (μm)	Mass Fraction (%) less than Stated Size			
	Before Re-application	Time After Reapplication		
		4 days	5 days	17 days
2,000	77	30	35	60
830	55	4.1	13	35
420	35	0.069	4.4	19
250	23	0.0087	1.5	9.4
180	17	-	0.67	6.0
150	13	-	0.36	4.3
100	9.2	-	0.12	2.3
75	5.8	-	0.034	1.6

For metals detected above a limit of detection in each sample of a set of three (e.g., the profiler filters from the Indiana Harbor Works or the subsilt samples from Armco), mean mass concentrations were determined. Tables III and IV present summary statistics for exposed filters and surface samples, respectively.

The values given for copper in Table IV are considered suspect because of contamination from the brass screens used in mechanical sieving. Comparison of split soil samples indicated that the copper concentration of the sample sieved 40 min was 360% greater than that of the 20 min sample. Tin concentrations also increased with sieving time. Thus, it appears that contamination of the sample occurs during mechanical sieving. Because nickel was not detected in any of the surface aggregate samples, it is not known if there is contamination associated with the nickel plated screens used in sonic sieving.

It is interesting to note the enrichment factors suggested by Tables III and IV. The mass concentration of an analyte is generally greater for the sample containing the finer particles. Thus, most of the analytes appear to be concentrated in the smaller size particulate.

TABLE III

SUMMARY STATISTICS FOR ICP ANALYSIS OF AIRBORNE PARTICULATE FROM UNCONTROLLED UNPAVED ROADS[a]
(concentrations in μg analyte/g particulate)

Analyte	Mean for Particulate Sampled by Profiler				Mean for Particulate Sampled by Cyclone			
	J&L[b]		Armco		J&L[b]		Armco	
Calcium	246,000	(25)	-[c]	-	310,000	(26)	-	-
Iron	75,900	(29)	67,600	(22)	80,400	(34)	32,800	(61)
Magnesium	-	-	-	-	42,800	(37)	-	-
Manganese	9,930	(30)	6,790	(15)	10,500	(34)	-	-
Titanium	1,790	(31)	-	-	1,930	(31)	-	-
Copper	385	(82)	-	-	701	(46)	-	-
Chromium	688	(25)	-	-	729	(33)	-	-
Barium	-	-	-	-	-	-	29,600	(80)
Zinc	-	-	57,600	(50)	-	-	28,900	(41)

[a] Value in parentheses represents relative standard deviation (%).

[b] These concentrations have been scaled using the mean rate of recovery for NBS Coal Fly Ash for the particular analyte if available, or by the average recovery rate for all the analytes detected in the samples.

[c] "-" indicates below detection limit.

TABLE IV

SUMMARY STATISTICS FOR ICP ANALYSIS OF UNCONTROLLED, UNPAVED ROAD SURFACE AGGREGATE SAMPLES[a]
(concentrations in μg analyte/g particulate)

Analyte	Mean Concentration for Silt (< 75 μm)				Mean Concentration for Subsilt (< 20 μm)			
	J&L[b]		Armco		J&L[b]		Armco	
Calcium	446,000	(7.9)	83,700	(38)	548,000	(6.3)	111,000	(8.2)
Iron	153,000	(16)	> 96,400	(NA)	250,000	(21)	66,100	(3.3)
Magnesium	75,900	(13)	13,900	(39)	94,300	(2.5)	12,000	(7.1)
Manganese	30,500	(15)	14,900	(16)	39,200	(16)	8,760	(5.4)
Aluminum	13,400	(7.6)	18,800	(51)	16,700	(5.2)	27,800	(8.6)
Potassium	-		6,290	(16)	-		8,370	(7.6)
Titanium	3,660	(17)	1,390	(9.4)	6,580	(8.5)	2,410	(6.2)
Sodium	1,190	(19)	2,300	(42)	1,680	(19)	3,560	(7.3)
Chromium	1,760	(17)	2,230	(14)	2,420	(24)	1,240	(3.5)
Zinc	645	(40)	1,730	(9.6)	1,050	(88)	1,920	(15)
Boron	159	(21)	-		196	(21)	-	
Lead	-		331	(29)	-		418	(8.5)
Barium	145	(7.6)	262	(64)	176	(5.3)	426	(7.9)
Copper[c]	121	(39)	115	(27)	872	(88)	160	(9.5)
Nickel	-		86.1	(17)	-		52.7	(17)
Yttrium	-		-		38.1	(17)	-	

[a] Value in parentheses represents relative standard deviation (%).

[b] Concentrations scaled in the same manner as in Table III.

[c] There is evidence of copper contamination during mechanical sieving, as discussed in the text.

As can be seen from Tables III and IV, trace metal concentrations in the filter samples tend to increase with increases in the concentration in the surface sample. The two exceptions are zinc and barium. The concentrations in these metals in the filter samples are much greater than the concentrations in the surface samples.

With the exceptions of copper, zinc, and barium, it was found that an essentially linear relationship between downwind airborne and surface aggregate mass concentrations is indicated by the limited data available here:

$$C_a = k\,(C_s)^P \qquad (3)$$

where C_a = airborne mass concentration (μg analyte/g particulate)

C_s = mass concentration of surface aggregate (μg analyte/g particulate)

k, P = regression parameters as follows:

Sample		Regression Parameters			
Air Sampler	Surface Aggregate	k	P	Number of Data Points	Correlation Coefficient
Profiler	Silt	0.297	1.04	6	0.997
Cyclone	Subsilt	0.129	1.10	7	0.994

Because of these relationships, it appears possible to economically estimate airborne elemental mass concentrations by examining the corresponding concentrations in the surface material. However, more data are required to substantiate such an approach.

CONCLUSIONS

Earlier studies of the effectiveness of unpaved road dust suppressants have indicated that reducing particulate emissions from this type of source may result in significantly improved air quality at a substantially lower cost compared to the further reduction of process source emissions. However, these earlier studies were directed toward quantifying initial

effectiveness soon (1 to 2 days) after application. Although decay in effectiveness was usually noticed, data obtained so shortly after application do not adequately characterize the chemical suppressant's long-term performance as commonly applied in the iron and steel industry.

Long-term dust suppression data are needed in order to develop effective programs for reducing dust emissions from unpaved roads. These data are necessary to determine (a) average emission reduction over a period of time, (b) the frequency of application required to achieve a specific average emission reduction, and (c) the cost-effectiveness of the particular dust suppressant.

This paper has presented long-term emission control efficiency values associated with dust suppressants currently in use at iron and steel plants. The results indicate that the chemical suppressants tested, when applied at the dilution ratio and application intensity recommended by the manufacturer, are capable of significantly reducing particulate emissions for at least one month (under the traffic rate during testing). Furthermore, the lifetime of a chemical suppressant appears to increase dramatically when reapplied. However, the lifetime of a suppressant tends to decrease with decreasing particle size.

Enrichment factors were noticed for most of the trace metals detected in the chemical analysis. The mass concentration of an analyte is generally greater for the sample containing the finer particles.

Essentially linear relationships were found between downwind airborne and surface aggregate mass concentrations for the majority of the trace elements detected in the chemical analysis of uncontrolled, unpaved road dust emissions. Because of these relationships, it appears possible to economically estimate airborne elemental mass concentrations by examining the corresponding concentrations in the surface material. However, more data are required to substantiate such an approach.

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